Distribution, Abundance and Population Structuring of Beaked Whales in the Great Bahama Canyon, Northern Bahamas

Diane Elaine Claridge
Bahamas Marine Mammal Research Organisation
P.O. Box AB-20714
Marsh Harbour
Abaco, Bahamas
phone: (242) 366-4155 fax: (242) 366-4155 email: dclaridge@bahamaswhales.org

John William Durban, Ph.D.
NOAA Southwest Fisheries Science Center
3333 N. Torrey Pines Court
La Jolla, CA 92037
phone: (858) 334-2866 email: John.Durban@noaa.gov

Award Number: N000140710120
http://www.bahamaswhales.org

In collaboration with:

Phillip Morin, Ph.D.
NOAA Southwest Fisheries Science Center
3333 N. Torrey Pines Court
La Jolla, CA 92037
Award Number: N0001409IP20051

Gina Ylitalo & David Herman, Ph.D.
NOAA Northwest Fisheries Science Center
2725 Montlake Blvd. East
Seattle, WA 98112
Award Number: N0001409IP20089

LONG-TERM GOALS

Atypical mass strandings and behavioral responses of beaked whales have been correlated with naval sonar (e.g. Simmonds and Lopez-Juraco 1991; Frantzis 1998; Evans and England 2001, Cox et al. 2006, Tyack et al. 2011), highlighting a need for a fuller understanding of beaked whale population ecology. This project is filling key data gaps on the distribution, abundance, and population structuring of beaked whales in the Great Bahama Canyon. The study area includes (1) the US Navy's Andros-AUTEC Operating Areas where fleet readiness training involves regular use of mid-frequency active sonars and (2) coastal waters off southwest Abaco Island where data exist from a 15-year photo-identification study, and where the March 15th, 2000 stranding occurred.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2012**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Distribution, Abundance and Population Structuring of Beaked Whales in the Great Bahama Canyon, Northern Bahamas**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Bahamas Marine Mammal Research Organisation P.O. Box AB-20714 Marsh Harbour Abaco, Bahamas**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**19**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

OBJECTIVES

The objectives of the study were:

1) To use visual line-transect surveys to document beaked whale distribution and estimate relative abundance and density.
2) To fit mark-recapture models to photo-identification data for Blainville's beaked whales (*Mesoplodon densirostris)* to estimate abundance, including comparisons before and after the 2000 stranding, and on / off the AUTEC range.
3) To collect skin and blubber biopsy samples to investigate beaked whale diet through fatty acid, stable isotope and contaminant analyses; and stock structure using molecular genetic approaches.

APPROACH

A multi-faceted approach has been used to investigate aspects of beaked whale population ecology in the northern Bahamas (Figure 1). Data collected from ship-based line transect surveys were used to estimate relative abundance and density of beaked whales in the Great Bahama Canyon. During ship surveys, skin and blubber biopsies were collected from whales throughout the larger geographic area to assess inter-species differences in habitat use, investigate diet and population structuring. Small vessel surveys operated in localized, coastal areas to collect individual-based data, including biopsy sampling but also focused on collecting photo-identification data for use in mark-recapture abundance estimates, building on the longitudinal data collected off Abaco Island since 1991. This work also occurred in coastal regions outside the Great Bahama Canyon to further assess population structuring.

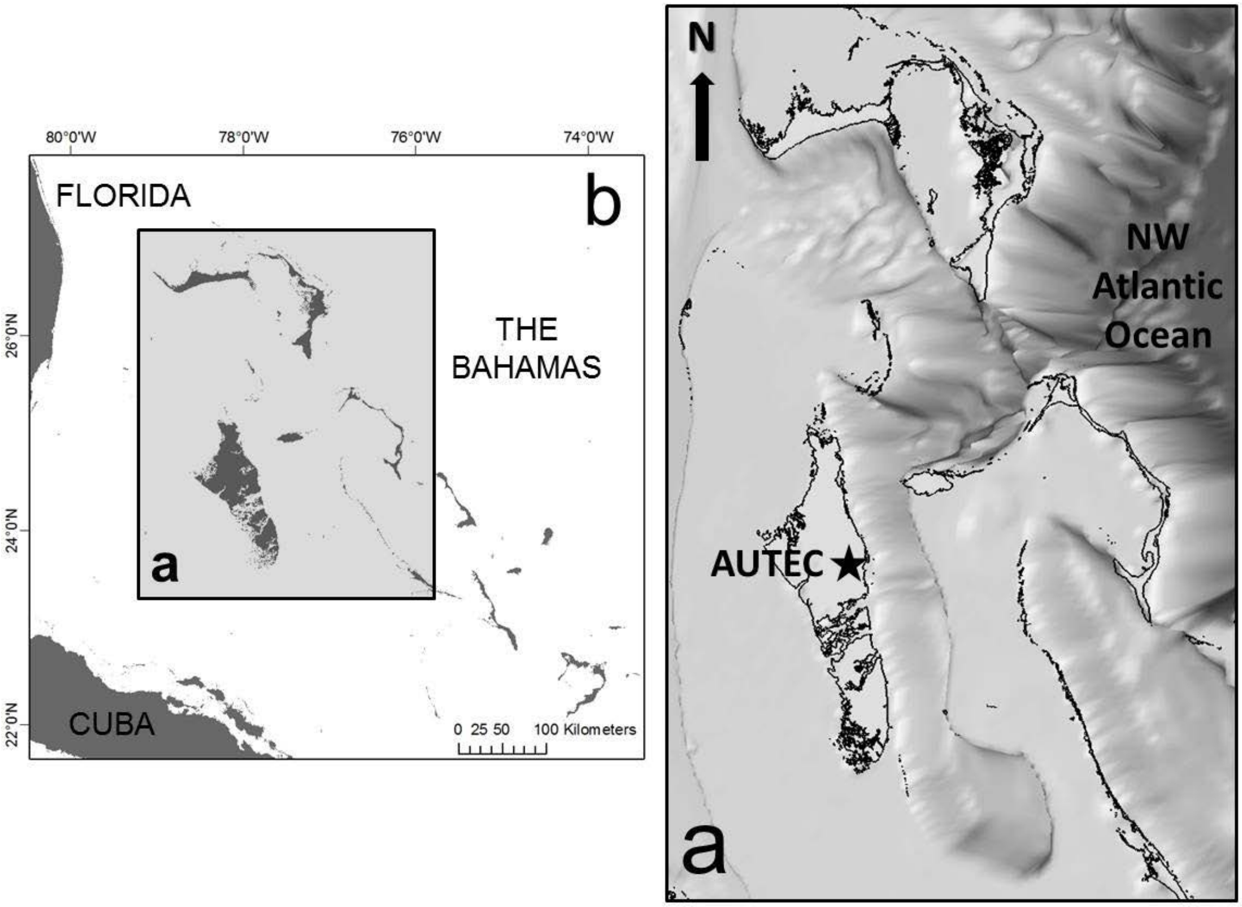

Figure 1. The Great Bahama Canyon (a) is a large submarine canyon located in the northern Bahamas (b). From the northwest Atlantic Ocean, the canyon has two branches; northwards into Northwest Providence Channel where the March 2000 atypical stranding occurred, and southwards through Northeast Providence Channel into Tongue of the Ocean and the Cul de Sac where the US Navy's Andros-AUTEC OpAreas are located. It reaches depths of more than 4000 m and is shown here with 20 times vertical exaggeration (data: GEBCO 2008).

Line transect surveys in the Great Bahama Canyon

Using standardized line-transect methods (Buckland *et al.* 2001; Zerbini *et al.* 2007), three ship-based visual and acoustic surveys were completed in FY07-08 to assess patterns of distribution and relative abundance in the Great Bahama Canyon. Transect lines were randomly placed within four rectangular strata (NE Providence Channel, NW Providence Channel, Tongue of the Ocean and the Cul de Sac (Figure 2)) using a saw-tooth pattern to allow equal area coverage and ensure that the track lines randomly sampled the study area. Visual observers were positioned on an observation platform (5 – 6 m height above sea level) and used fixed-mount Fujinon 25x magnification binoculars to scan from 90° on each side of the ship and overlap 10° off the bow to provide greater coverage of the track line. Line transect data were analyzed using the program Distance and multi-covariate distance sampling was used to test effects of different variables on detection probability (Thomas *et al.* 2009).

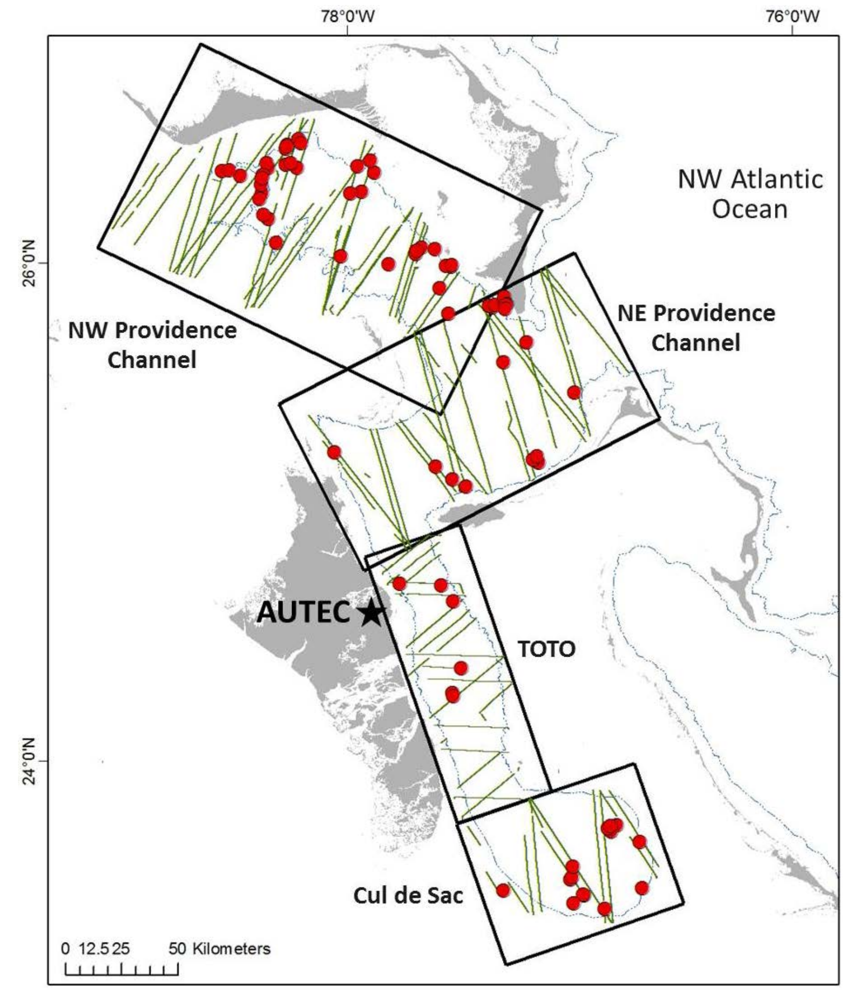

Figure 2. Equal-angle line transects were run in four strata covering the Great Bahama Canyon (ship tracks are green lines). Red circles represent locations of beaked whale sightings used to build the detection function and estimate abundance and density. The 1,000 m isobath is shown as the blue line.

Upon sightings, the ship broke off the transect line for a close approach to groups when necessary to confirm species identification and to estimate group size. Closing mode was adopted for all sightings of beaked whales to collect individual identification photographs (Figure 3) and to carry out remote biopsy sampling (e.g. Barrett-Lennard *et al.* 1996).

Figure 3. Photo-identification images of Md091, an adult female Blainville's beaked whale (Mesoplodon densirostris) from the Abaco study area, demonstrating that the longevity of natural markings in this species. Oval marks are scars from bites attributed to cookie cutter sharks (Isistius spp.).

<u>Concentrated vessel surveys inside and outside GBC</u>

To increase the number of biopsy samples obtained and facilitate comparisons in habitat use, residency, and population genetics between five different regions within the Great Bahama Canyon, an additional fourth ship survey was conducted in FY09 during which the ship returned to areas of highest concentration of beaked whales. Small vessel surveys were also conducted in FY07, FY11 and FY12 off the southwest coast of Abaco Island, where longitudinal photo-identification data exist, to contribute to mark-recapture analysis and collect biopsy samples for contribution to the population genetics study (as well as other ONR-funded projects). Additionally, small vessel surveys were conducted outside the Great Bahama Canyon during FY10 (in Exuma Sound and the Great and Little Abaco Canyons) to evaluate population structuring and movement patterns of beaked whales (Figure 4).

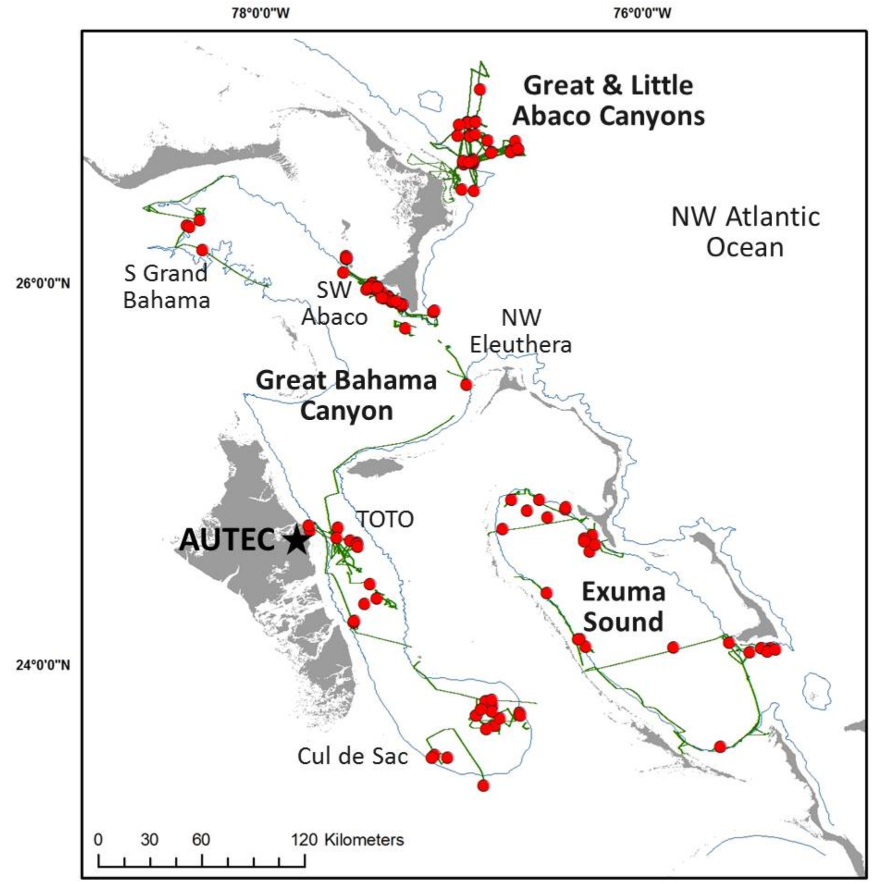

Figure 4. Map of the northern Bahamas showing the tracklines (green lines) from vessel surveys focused in areas determined to have high beaked whale concentrations to increase biopsy and photo-identification sample sizes. Red circles represent sighting locations of beaked whale groups. Surveys were conducted are five locations inside the Great Bahama Canyon as well as two areas outside (Great and Little Abaco Canyons and Exuma Sound). The 1,000 m isobath is shown as the blue line.

<u>Application of photo-identification data</u>

Open-population mark-recapture models were fit to the photographic data to estimate abundance and turnover (emigration from and re-immigration back into the study area) of Blainville's beaked whales using a parametric Bayesian approach. Abundance and turnover were compared in two areas of equal size (~300 km^2) on and outside the Atlantic Undersea Test and Evaluation Center (AUTEC). Using methodologies developed adopted by Matkin *et al.* (2012), mark-recapture models were fit to photo-identification data collected during 6 years (2005-2010) at AUTEC, where mid-frequency active sonars are used regularly; and off the SW coast of Abaco Island (~170 km away, Figure 4), considered a control study site where navy sonar is not used regularly. Bayesian mark-recapture models also are being fit to photo-identification data collected off the southwest coast of Abaco Island from 1997 to 2011 to investigate longer-term trends in abundance of Blainville's beaked whales, spanning the time period before and after the March 2000 stranding; these analyses are still underway. Additionally, photo-identification data were used to assess movement of individual whales between survey locations during the study.

Analyses of biopsy samples
Tissue samples collected during this study and previously archived in the Bahamas are being used for population genetic structure analyses of beaked whales by Dr. Phillip Morin and colleagues at the Marine Mammal Genetics Group at NOAA's Southwest Fisheries Science Center. The samples consist of skin biopsies, sloughed skin, feces, and bone collected from beaked whales from around the northern Bahamas. A portion of the mitochondrial control region that has previously been used for phylogenetic studies of beaked whales was sequenced, and sexing of all samples has been done using a real-time PCR based method. In addition, single nucleotide polymorphism (SNP) markers were developed at which to genotype all samples. These data are being used to investigate gene flow and population substructuring around the sampled regions, while estimates of relatedness and phylogeography will be used to evaluate site fidelity and social structure. These analyses are still underway.

Chemical analyses of skin and blubber biopsies were conducted by Dr. David Herman and his colleagues at the Environmental Assessment Program at NOAA's Northwest Fisheries Science Center (under guidance from Gina Ylitalo, Program Manager). Nitrogen and carbon stable isotope ratios (SI) in skin were analyzed in biopsy samples from beaked whales to investigate habitat use, while blubber fatty acids (FA) were analyzed to assess diet. Analyses were also conducted for Persistent Organic Pollutants (POPs) in order to further elucidate foraging habits and population structure. The analytical methods used to analyze these samples for FAs, SIs, and POPs are described in Herman *et al.* (2005) and Sloan *et al.* (2005).

WORK COMPLETED

Data Collection
Between October 2006 and May 2012, this study has surveyed over 17,000 km in the northern Bahamas (Table 1). This effort has resulted in sightings of 205 beaked whale groups, including three species: Blainville's beaked whale (*Mesoplodon densirostris*, n=104), Gervais' beaked whale (*M. europaeus*, n=24), and Cuvier's beaked whale (*Ziphius cavirostris*, n=53). During these encounters, there were 106 biopsy samples collected from beaked whales.

Table 1. Summary of vessel effort and data collected during encounters with beaked whales in the northern Bahamas, 2006 – 2012. The distance travelled and groups seen during line transects in the Great Bahama Canyon are given in parentheses.

Area	Effort (km)	Number of groups sighted	Number of biopsy samples
Great Bahama Canyon	8,885 (3,687)	126 (75)	56
SW Abaco coast	4,675	28	8
Exuma Sound	1,526	15	0
Great and Little Abaco Canyons	2,587	36	42

Mark-recapture Analyses
Photographs of Blainville's beaked whales (*M. densirostris*) were graded for quality and individuals were rated on presence or absence of notches in the dorsal fin. Identification histories were compiled for each individual whale, consisting of a binary history over a series of annual sampling intervals which extended from March through October within the study period where concurrent effort was possible at AUTEC and Abaco (2005-2010). During this interval, there were 44 distinctively-marked whales identified from high-quality photographs at Abaco and 29 at AUTEC; notably no individuals were seen in both study sites, providing some evidence for population structuring. The majority of whales at both sites were only seen in one year (median = 1, maximum = 5 at Abaco; median = 1, maximum = 4 at AUTEC) (Figure 5). However, some individuals were seen in multiple years (15 whales at Abaco, 34% of the total; and 10 whales at AUTEC, 35% of the total), suggesting that at least some whales exhibit site fidelity.

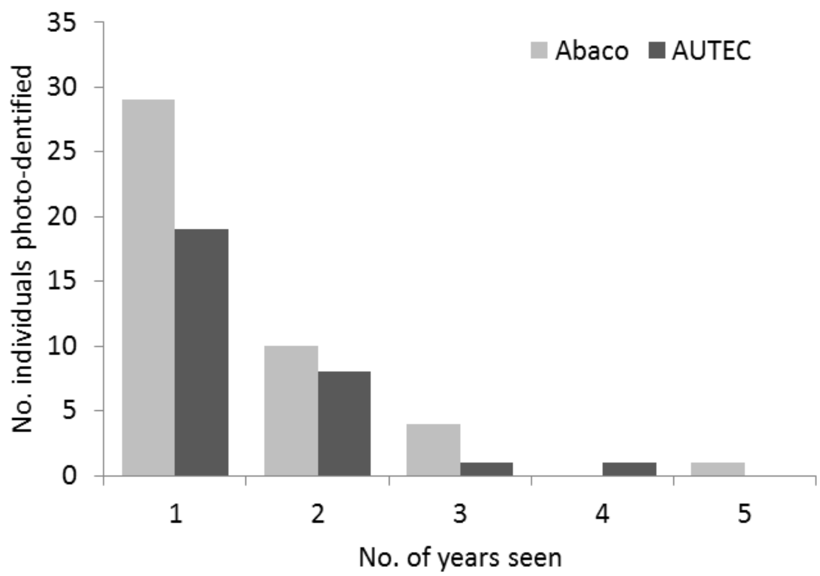

Figure 5. The number of years that individual, distinctive non-calf Blainville's beaked whales were photo-identified from high quality photographs during the annual sampling interval in years 2005 – 2010 for each area.

Photo-identification data were also analyzed from a longer data series collected off SW Abaco from 1997 – 2011. During this 15-years period, there were 157 groups of Blainville's beaked whales encountered during an annual sampling interval of May – August, resulting in 339 identifications. From these, seventy-five distinctly-marked individuals were identified, with the number of whales identified annually ranging from 6 to 17 (median=11). While the majority of whales were seen in more than one year of the 15-year study (median 2, maximum 11), all the individuals seen in more than six years were adult females, suggesting a different residency pattern for this age /sex class. For this reason, age structured heterogeneity is being investigated to understand its effect on capture probabilities. Results of model fitting are expected soon, including abundance and survival trends.

High-quality photo-identifications of beaked whales from each survey area were compared to document movements between sites. In all, there were 366 Blainville's beaked whales, 49 Gervais' beaked whales, and 111 Cuvier's beaked whales identified during the study.

Genetic Analyses

The Marine Mammal Genetics Group (SWFSC) have completed sequencing of complete mitochondrial genomes and ~60 nuclear loci on a set of 23 *M. densirostris*, 23 *Z. cavirostris*, and 9 *M. europaeus* samples, and used the data for analysis of mitogenomic diversity and phylogenetics. Additionally, nuclear SNP discovery was conducted for both *M. densirostris* and *Z. cavirostris*, resulting in assay design for 59 *Z. cavirostris* SNPs and 58 *M. densirostris* SNPs. Genotyping was completed for approximately 80 *Z. cavirostris* samples for all of the SNP assays, 53 of which have resulted in usable genotypes. Genotyping of these 53 assays on approximately 80 additional *Z. cavirostris* samples will be completed in late 2012, and assay optimization and genotyping of *M. densirostris* will begin by the end of the calendar year. It is expected that genotyping will be complete for both species by the end of the first quarter in 2013, at which time the Genetics Group will conduct relatedness and population structure analyses.

Chemical Analyses

Of the 106 biopsies collected, blubber/skin samples from 48 beaked whales (*M. densirostris*, n=28; *Z. cavirostris*, n=19; and *M. europaeus*, n=1) were analyzed for their nitrogen and carbon stable isotope ratios (SIs) , blubber fatty acids (FAs), persistent organic pollutants (POPs), and lipid class compositions. One randomly selected sample from each species was used to analyze lipid class composition. Table 2 summarizes the samples that were included in the chemical analyses.

Table 2. Summary information for blubber/skin biopsy samples analyzed for chemical markers. [a] Sex and age classes determined by visual observation. [b] Indicates whales having dietary fatty acid profiles identified by principal component analyses to be outliers and therefore excluded in subsequent analyses.

Sample#	Specimen ID#	Sex[a]	Age Class[a]	Collection location/ foraging region	Collection date	Excluded[b]
Blainville's Beaked Whales						
1	070611_Md1b	Female	Adult	SW Abaco	6/11/2007	
2	080522_Md1a	Female	Adult	TOTO	5/22/2008	
3	080608_Md2a	Female	Adult	SW Abaco	6/8/2008	
4	080611_Md2a	Female	Adult	S Grand Bahama	6/11/2008	
5	080611_Md3a	Female	Adult	S Grand Bahama	6/11/2008	
6	080611_Msp1a	Female	Adult	S Grand Bahama	6/11/2008	
7	080614_Md2a	Female	Adult	SW Abaco	6/14/2008	
8	080614_Md5a	Female	Adult	SW Abaco	6/14/2008	
9	080614_Md6a	Female	Adult	SW Abaco	6/14/2008	
10	090508_Md2a	Female	Adult	TOTO	5/8/2009	
11	090602_Md2a	Female	Adult	S Grand Bahama	6/2/2009	
12	070608_Md1c	Male	Adult	SW Abaco	6/8/2007	
13	071005_Md1a	Male	Adult	Cul deSac	10/5/2007	
14	080522_Md2a	Male	Sub-Adult	TOTO	5/22/2008	b
15	080608_Md1a	Male	Adult	SW Abaco	6/8/2008	
16	080611_Md1a	Male	Adult	S Grand Bahama	6/11/2008	
17	080613_Md1a	Male	Sub-Adult	SW Abaco	6/13/2008	
18	080614_Md1a	Male	Adult	SW Abaco	6/14/2008	
19	080614_Md3a	Male	Sub-Adult	SW Abaco	6/14/2008	b
20	090507_Md1a	Male	Adult	TOTO	5/7/2009	
21	090526_Md1a	Male	Adult	Cul deSac	5/26/2009	
22	090530_Md1a	Male	Adult	TOTO	5/30/2009	
23	090531_Md1a	Male	Adult	NW Eleuthera	5/31/2009	
24	090602_Md1a	Male	Adult	S Grand Bahama	6/2/2009	
25	080611_Msp2a	Unknown	Juvenile	S Grand Bahama	6/11/2008	
26	080611_Msp3a	Unknown	Sub-Adult	S Grand Bahama	6/11/2008	
27	090505_Md1a	Unknown	Adult	SW Abaco	5/5/2009	
28	090508_Md1a	Unknown	Unknown	TOTO	5/8/2009	
Cuvier's Beaked Whales						
29	071005_Zc1a	Female	Adult	Cul deSac	10/5/2007	
30	080603_Zc1a	Female	Adult	NW Eleuthera	6/3/2008	
31	080610_Zc2a	Female	Adult	S Grand Bahama	6/10/2008	
32	080611_Zc5a	Female	Adult	S Grand Bahama	6/11/2008	
33	090506_Zc1a	Female	Adult	NW Eleuthera	5/6/2009	
34	090506_Zc2a	Female	Adult	NW Eleuthera	5/6/2009	
35	080602_Zc1a	Male	Adult	NW Eleuthera	6/2/2008	
36	080603_Zc2a	Male	Adult	NW Eleuthera	6/3/2008	
37	080610_Zc3a	Male	Adult	S Grand Bahama	6/10/2008	
38	080611_Zc3a	Male	Adult	S Grand Bahama	6/11/2008	
39	080611_Zc4a	Male	Adult	S Grand Bahama	6/11/2008	
40	080611_Zc7a	Male	Adult	S Grand Bahama	6/11/2008	b
41	090528_Zc1a	Male	Adult	Cul deSac	5/28/2009	
42	090529_Zc2a	Male	Adult	Cul deSac	5/29/2009	
43	080610_Zc5a	Unknown	Sub-Adult	S Grand Bahama	6/10/2008	
44	080611_Zc1a	Unknown	Sub-Adult	S Grand Bahama	6/11/2008	
45	080611_Zc6a	Unknown	Juvenile	S Grand Bahama	6/11/2008	
46	090528_Zc2a	Unknown	Adult	Cul deSac	5/28/2009	
47	090529_Zc1a	Unknown	Adult	Cul deSac	5/29/2009	
Gervais' Beaked Whale						
48	071004_Me1a	Female	Adult	Cul deSac	10/4/2007	

PRELIMINARY RESULTS

Beaked whale density

Ship surveys in the Great Bahama Canyon resulted in 75 on-effort sightings of beaked whales (Figure 2) which were used to build our detection function. These comprised 3 species: Blainville's beaked whale (*M. densirostris*, n=42), Gervais' beaked whale (*M. europaeus*, n=3) and Cuvier's beaked whale (*Ziphius cavirostris*, n=20), plus 10 sightings where species was undetermined. Effects of ship platform and observer on detection probability were minimal but sea state had a large effect and was added as a factor variable to the detection function. The resulting detection function fit the data well (K-S test, p=0.93) with a truncation distance of 3,000m. Thirty-five sightings occurred on the path of the transect lines with a mean cluster size of 2.71 (SE 0.22). Overall estimates of abundance and density of Mesoplodon beaked whales in the Great Bahama Canyon were 1,426 whales and 51.1 beaked whales/1000 km2 (CV 0.40). Abundance and density estimates for Ziphius were 1,380 whales and 49.5 beaked whales/1000 km2 (CV 0.49).

Relative density of beaked whales varied by strata, although differences are not significant due to high coefficients of variance (Table 3). The highest densities were found in NW Providence Channel, providing some context to interpret the potential impact of the 2000 stranding and also in the Cul de Sac, which despite being part of the Andros-AUTEC OpArea, is an acoustically "quiet" region and is currently not used for tactical sonar exercises.

Table 3. Relative density of beaked whales of the genera Mesoplodon and Ziphius by strata in the Great Bahama Canyon (whales/1000 km^2 (CV).[1] Estimates are pooled for M. densirostris and M. europaeus.

Strata	Mesoplodons	Ziphius
NW Providence Channel	57.6 (0.50)	80.0 (0.67)
NE Providence Channel	39.3 (0.55)	15.5 (1.03)
Tongue of the Ocean	39.5 (0.65)	n/a
Cul de Sac	73.4 (0.61)	109.0 (0.65)

Comparing abundance and turnover on and off Navy range

Open-population models were fit to photo-identification data from AUTEC and SW Abaco and model selection supported inclusion of parameters for temporary emigration and re-immigration to the study area in addition to mortality. The annual probability of emigration, re-immigration, and survival of distinctive whales (mostly adults) was similar at the two sites. However, there was a high probability (p=0.90) that average annual abundance was lower at the navy range. Average annual abundance estimated at AUTEC was 30 whales (75% Highest Posterior Density Intervals [HPDI] = 22-40) compared to 64 whales at Abaco (75% HPDI = 49-81). Photographic assessment of age classes revealed fewer immature animals on the navy range and, despite a comparable number of adult females at AUTEC, fewer calves were observed. Low recruitment appears to be contributing to relatively low abundance at AUTEC, warranting further investigation.

Re-sightings and movements

[1] The authors wish to acknowledge Dr. Len Thomas (U St Andrews) and Dr. Jay Barlow (Southwest Fisheries Science Center) for their contribution to these analyses.

Using high-quality photographs, re-sightings of individuals were recorded for all three beaked whale species, with long-term re-sightings of Blainville's beaked whales (16 years) and Cuvier's beaked whales (11 years). The number of individuals re-sighted were 153 Blainville's (41.8%), 15 Cuvier's beaked whales (13.5%), and 6 Gervais' beaked whales (12.2%). Movements between surveys areas were documented for individual Blainville's beaked whales and Cuvier's beaked whales, but not for Gervais' beaked whale (Figure 6). Movements primarily were made by adult males & immature animals. Notably there were no matches or records of movement between areas within the Tongue of the Ocean and any other area outside TOTO. One of the Ziphius re-sightings was of an adult female that live stranded during the March 2000 atypical stranded event. This individual (Zc027) was pushed off the beach by rescuers in SW Abaco on March 15, 2000. It was later re-sighted with a dependent calf off NW Eleuthera on May 6, 2009 providing documentation of having survived the stranding as well as remaining in the same general area post-stranding. There were 6 re-sightings made of Gervais' beaked whales during the study, but no movements between areas documented.

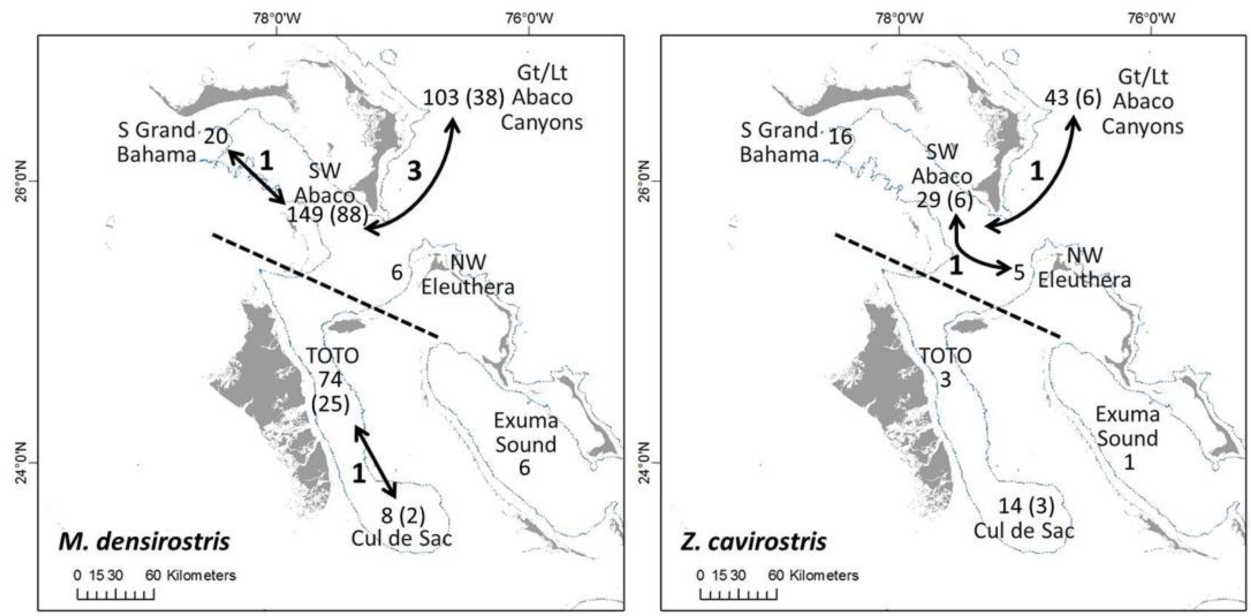

Figure 6. Map of the northern Bahamas showing the total number of whales that have been assigned to photo-identification catalogues for each area, for Blainville's beaked whales (on left) and Cuvier's beaked whales (on right). The number of re-sightings of individuals within the same area is shown in parentheses, while the documented movements of individuals between areas are shown as bold numbers with arrows associated with each. The dashed line represents the lack of recorded movement between the northern branch of the Great Bahama Canyon and Tongue of the Ocean for both species.

<u>Population genetics</u>

The preliminary results of the genetics analyses to date were presented as a report to the small cetacean committee at the International Whaling Commission (Morin *et al.* 2012) in June 2012. Key findings reported were that for *M. densirostris* haplotypes were divided into two clades, representing the western Atlantic and the Pacific, while for *Ziphius*, there were three major clades. However for the Ziphius, samples from the Atlantic were found in all three clades, and samples from the Pacific were found in two of the clades, while no haplotypes were shared between ocean basins for either species.

This complex pattern in *Ziphius* suggests either multiple inter-ocean migration events in recent evolutionary history, or possibly current gene flow between ocean basins (Morin *et al.* 2012).

Chemical tracers

Lipid class composition analysis found lipids were composed entirely of wax/sterol esters at all blubber depths. The patterns of dietary fatty acids are notably different among the three species of beaked whales (Figure 7), suggesting that they feed on largely different prey. Stable isotopes ratios also differed among species, with higher 15N isotope values and lower 13C isotope values found in Blainville's than in Cuvier's beaked whales ($p<0.05$), suggesting that Cuvier's whales not only feed upon prey that is different from the Blainville's whales, but also feed in different habitat, possibly greater depths. Differences in isotope ratios were also found among foraging regions suggesting that whales feed repeatedly within localized areas rather than foraging throughout the entire Great Bahama Canyon study area. Mark-recapture analysis of photo-identification data has also shown site-fidelity of Blainville's beaked whales to the AUTEC range in Tongue of the Ocean and to long-term study sites off Abaco, providing further support for population structuring on a relatively small spatial scale.

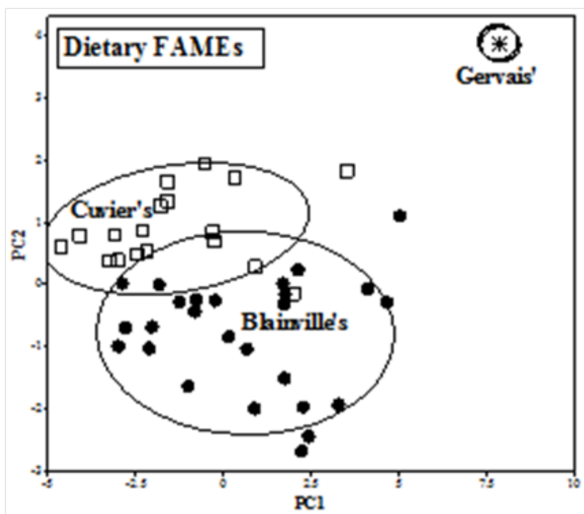

Figure 7. Principal Component Analysis plot depicting the differences in dietary fatty acid profiles among Blainville's (closed symbols), Cuvier's (open symbols), and Gervais' (asterisk) beaked whales. Ovals represent the 80% probability density intervals for each species.

The POP patterns (and ratios) were assessed for five sampling regions for adult male Blainville's beaked whales and Cuvier's beaked whales (Figure 8). Despite sample size constraints, there are some indications that the POP patterns differ geographically for Blainville's and Cuvier's, suggesting that both these species exhibit some degree of long-term foraging site fidelity.

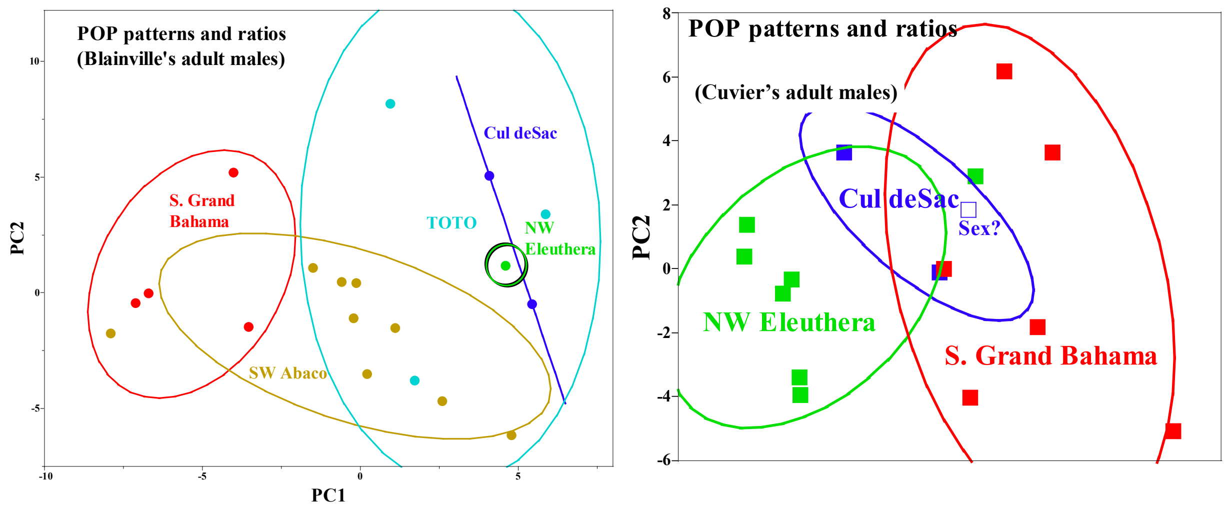

Figure 8. Principal Component Analysis plots depicting the differences in POP profiles (and ratios) among five sampling/foraging locations for adult male Blainville's beaked whales (left) and adult male Cuvier's beaked whales (right). Ovals represent the 80% probability density intervals at each location.

Analysis of absolute lipid-normalized concentrations of POPs suggests only slight inter-species differences. The levels of contamination in the Bahamas whales were not inordinately high and for the most part comparable to levels found in Baird's beaked whales (*Berardius bairdii*) from the central Aleutian Islands (Table 4) and in resident killer whales (*Orcinus orca*) in the Gulf of Alaska.

Table 4. Comparison of contaminant concentration levels (ng/g lipid) between Blainville's and Cuvier's beaked whales sampled in the Great Bahama Canyon. These levels were similar to those recorded for Baird's Beaked whale sampled in the Central Aleutian Islands, Alaska. Results do not include reproductive females.

Contaminant	Blainsville's (n=15)	Cuviers' (n=11)	Baird's Beaked[a] (CAI) (n=7)
	Mean Stdev	Mean Stdev	Mean Stdev
ΣPCB's	14100 ± 8600	15800 ± 6400	12000 ± 4600
ΣDDT's	16800 ± 12200	22000 ± 10000	15000 ± 7500
ΣCHLR's	2020 ± 1300	2030 ± 800	1600 ± 700
ΣHCH"s	12 ± 14	4.0 ± 6.7	64 ± 34
ΣPBDE's	500 ± 400	300 ± 120	5 ± 8

a) Contaminant levels measured in Baird's Beaked Whales biopsy sampled in the Central Aleutian Islands (AK) during the spring/summer of 2003 (NWFSC unpublished results)

Since there was no significant difference in concentrations of POPs between the beaked whale species from the Bahamas (Table 4), POP results for these two species were pooled together and the mean concentrations computed at each of the five sampling locations (not including reproductive-age females). Differences were found between these geographic regions as shown in the summary POP concentration data in Table 5. Despite sample size constraints, the mean POP concentration levels at

NW Eleuthera, TOTO, and in the Cul de Sac regions are similar and approximately two times higher than concentrations measured in animals from S. Grand Bahama and SW Abaco. The higher levels measured in these three locations suggests the existence of a POP "hot-spot" somewhere in Northeast Providence Channel and/or TOTO.

Table 5. Comparison of contaminant concentration levels (ng/g lipid) among the five sampling sites in the Great Bahama Canyon. Blainville's and Cuvier's beaked whales are pooled in this comparison. Results do not include reproductive females.

Contaminant	NW Eleuthera (n=3)	TOTO (n=3)	Cul deSac (n=4)	S.Grand Bahama (n=11)	SW Abaco (n=5)
	Mean Stdev	Mean Stdev	Mean Stdev	Mean Stdev	Mean Stdev
ΣPCB's	22000 ± 5000	20000 ± 13000	16000 ± 7000	13000 ± 7000	10000 ± 6400
ΣDDT's	29000 ± 6000	26000 ± 20000	21000 ± 11000	17000 ± 11000	12000 ± 10000
ΣCHLR's	2900 ± 310	2900 ± 1700	2300 ± 1400	1800 ± 900	1400 ± 800
ΣHCH"s	15 ± 10	23 ± 21	13 ± 13	2.9 ± 7.6	4.6 ± 6.7
ΣPBDE's	340 ± 30	810 ± 550	680 ± 460	310 ± 170	240 ± 120

IMPACT/APPLICATIONS

This project is providing key information on the baseline population ecology of beaked whales in the Great Bahama Canyon to better understand and help mitigate the impacts of naval activities within this area. High densities of beaked whales were found in the Cul de Sac region of the Andros-AUTEC Operating Areas which has implications for its future management uses.

Chemical analyses and photographic mark-recapture findings suggest site fidelity and fine-scale population structuring of beaked whales. Currently very little is known about the foraging behavior of beaked whales, and the results of this study suggesting dietary differences between sympatric species represents a significant advance in our understanding of the trophic dynamics and feeding ecology of these whales. We report lower abundance and recruitment of Blainville's beaked whales at AUTEC than at the SW Abaco study area but further investigation is needed to understand whether this reflects habitat differences or a population response to Navy activities at AUTEC. Tyack *et al.* (2011) report movements of beaked whales off range in response to multi-ship tactical sonar exercises at AUTEC which may lead to potential population level effects.

The population genetics work will investigate gene flow, population structuring, relatedness and phylogeography to evaluate site fidelity and social structure; and will provide further information on the extent and scale of population structuring of beaked whales in this area. Combined these data will be used to better understand habitat use and movement patterns; both will be related to the possible effects of exposure to Navy sonar on the AUTEC range.

RELATED PROJECTS

Monitoring beaked whale movements during the Submarine Commanders Course using satellite telemetry

This project is a collaborative project between the Bahamas Marine Mammal Research Organisation, Southwest Fisheries Science Center and the Naval Undersea Warfare Center (David Moretti). Satellite telemetry is being used to monitor the movements and diving behavior of beaked whales and other odontocete cetacean species on the US Navy's Atlantic Undersea Test and Evaluation Center (AUTEC) range before, during and after sonar exercises in which multiple ships are using their tactical sonars. Field work during this project is providing opportunity to collect biopsy samples and photo-identification data at AUTEC which has contributed to the AUTEC-Abaco abundance comparsion. Tags were deployed outside AUTEC during the 2009 GBC beaked whale survey. This project has been supported by the US Department of Defense (OPNAV N45, award no. N00244-12-1-0007).

Behavioral ecology of deep-diving odontocetes in the Bahamas
This project is examining key aspects of the behavioral ecology of six Department of Defense priority species in The Bahamas. All data collected for non-beaked whale species during the beaked whale surveys from 2007-2012 will be contributed to analyses as part of this transition project. We will integrate data acquired through individual photo-identification, molecular genetics, fatty acid, persistent organic pollutant and stable isotope profiles, satellite telemetry and acoustic recordings to characterize the social structure, residency patterns, reproductive biology, diet, foraging ecology, and population structuring of key cetacean species. The project has been supported by the Strategic Environmetal Research and Development Program (US Department of Defense, Department of Energy and the Environmental Protection Agency, RC-2114).

Assessing Beaked Whale Reproduction and Stress Response Relative to Sonar Activity at the Atlantic Undersea Test and Evaluation Center (AUTEC)
This project is a collaborative effort between Southwest Fisheries Science Center (Nick Kellar, lead) and the Bahamas Marine Mammal Research Organisation and aims to collect biopsy samples at the U.S. Navy's Atlantic Undersea Test and Evaluation Center (AUTEC) and compare the levels to those measured in biopsies collected from control populations within the Bahamas region that are less exposed to sonar activity. In parallel, pregnancy states will be ascertained via blubber progesterone levels in both groups of animals to investigate whether there is a relationship between sonar activity, stress measures, and reproductive rates, to assess population-level impacts. (ONR award no: N000141110433, N0001411IP20080).

Assessing stress response in beaked and sperm whales in the Bahamas.
This project is being led by Rosalind Rolland, DVM at the NE Aquarium in collaboration with the Bahamas Marine Mammal Research Organisation to develop the use of fecal steroid hormone assays to assess stress responses in Blainville's beaked whales and sperm whales (*Physeter macrocephalus*) in the northern Bahamas. These species were chosen to include a particularly acoustically-sensitive cetacean (beaked whales) and a co-occurring species (sperm whales) for comparison. The goal is to determine baseline fecal hormone levels for reference populations of these two deep-diving whale species, characterizing the natural variations in stress-related hormones according to life history stage (age, sex, reproductive status). The beaked whale ecology study provided funding leverage to the fecal steroid hormone assays study in 2011 in vessel use and personnel time (Rolland ONR award no. N000141110540).

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PUBLICATIONS

Data collected as part of this award have/are contributing to the following completed/planned publications:

Gillespie, D., Dunn, C. A., Gordon, J., Claridge, D. E., Embling, C. and Boyd, I. L. (2009). Field recordings of Gervais' beaked whales *Mesoplodon europaeus* from the Bahamas. J. Acoust. Soc. Am. 125(5).

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Morin, P.A., Duchene, S., Lee, N., Durban, J., Claridge, D. (2012). Preliminary analysis of mitochondrial genome phylogeography of Blainville’s, Cuvier’s and Gervais’ beaked whales. International Whaling Commission, Scientific Meeting 64, Panama City, Panama, SC/64/SM14.

Claridge et al. Comparing rates of turnover, abundance and age composition of Blainville’s beaked whale (*Mesoplodon densirostris*) on and off a navy range in The Bahamas.

Claridge et al. Abundance and survival trends of Blainville’s beaked whales (*Mesoplodon densirostris*) surrounding an atypical stranding in the Bahamas.

Claridge et al. Relative abundance and densities of beaked whales in the Great Bahama Canyon.

Claridge et al. Note on resightings of rescued beaked whales following the March 2000 stranding in the Bahamas.

Claridge et al. Using longitudinal photo-identification data for *Mesoplodon densirostris* age class determination.

(Note: Claridge’s work forms the basis of a Ph.D. dissertation at the University of St Andrews, to be completed in October 2012.)

Dunn et al. Blainville’s beaked whale neonate clicks at depth.

Dunn et al. Cues in Blainville’s beaked whale echolocation clicks to inform on animal sex.

Dunn et al. Blainville’s beaked whale social structure.

Durban et al. Movement scales and three-dimensional habitat use of odontocetes in the Great Bahama Canyon.

Durban et al. Movement and diving responses of Blainville's beaked whales exposed to Navy sonar.

Herman et al. Diet and niche differences between three sympatric beaked whale species in Great Bahama Canyon.

Herman et al. Chemical signatures support fidelity to small-scale foraging ranges of Blainville's beaked whales within Great Bahama Canyon.